

Simulation and Analysis of the Heat Pump System with Flash-Tank Coupled with Scroll Compressor

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Abstract: The heat pump system with flash-tank coupled with scroll compressor has good performances, especially under the conditions of low ambient temperature, by improving its internal compression process. The correlation of electric efficiency is fitted by least square method based on the experimental data of the heat pump prototype in which R22 is used as refrigerant. According to the correlation, the performances of the heat pump system have been simulated and analyzed under the conditions of the condensation temperature from 30°C to 50°C and the evaporation temperature from -30°C to 0°C. The results demonstrate as follows: the heating coefficient of performance of the heat pump system is 1.87, the discharge temperature of the compressor is less than 130°C, the power input is 4.44kW, and the heating capacity is 8.28kW, when the system with a 5Hp scroll compressor worked in the condition of the condensation temperature of 45°C and the evaporation temperature of -25°C. So the heat pump system with high efficiency will be an ideal alternative method for building heating in cold regions such as north China and Yellow River basin.

Keywords: heat pump, scroll compressor, performance simulation

NOMENCLATURE

Symbol	Description [Units]
P_k	Condensation Pressure [kW]
P_m	Medial Pressure [kW]
P_o	Evaporation Pressure [kW]
T_k	Condensation Temperature [°C]
T_o	Evaporation Temperature [°C]
T_d	Discharge Temperature [°C]
Q_h	Heating Capacity [°C]
W	Power Input [kW]

1. INTRODUCTION

For a long time, air-source heat pump system is applied widely in the regions such as middle and lower reaches of the Changjiang River, southwest and south China. It can satisfy heating and air conditioning requirements of these regions commendably because its energy consumption and initial investment are lower. It can be used in both summer and winter expediently and has no pollution. But for the regions such as Yellow River drainage area and north China, the ambient temperature is lower and heating period is longer in winter, so conventional air-source heat pump cannot satisfy the heating requirement. It appears that the heating coefficient of performance (COP_h) of the system is low and the discharge temperature of the compressor is so high that the system cannot work steadily. Hence, the conventional air-source heat pump cannot be used to cold regions if it is not improved.

To solve the above problems of air-source heat pump in cold regions, many researcher's have done a lot of work. The heat pump system with flash-tank

coupled with scroll compressor is an ideal project, which improves the heating coefficient of performance and capacity effectively^[1,2].

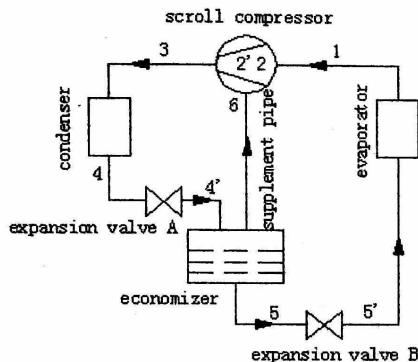
On the basis of experimental data of the heat pump prototype, in which R22 is used as refrigerant, the correlation of electric efficiency is fitted by least square method. According to the correlation, the performances of the heat pump system can be simulated and analyzed.

2. THE HEAT PUMP SYSTEM WITH FLASH-TANK COUPLED WITH SCROLL COMPRESSOR

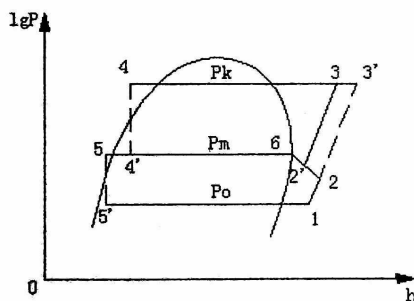
The heat pump system with flash-tank coupled with scroll compressor has good performances, especially under the conditions of low ambient temperature, by improving its internal compression process. The refrigerants in the main loop and the supplementary loop exchange heat to improve performance of the system.

The principle of the heat pump system with flash-tank coupled with scroll compressor is shown in Fig.1. In this system, scroll compressor with supplementary inlet is used. The superheated refrigerant with high temperature and pressure is discharged by a scroll compressor (3) and flows through the condenser, which transfers heat from the refrigerant to the cooling medium and becomes a saturated or sub-cooled liquid (4), the warming-up cooling medium can be used for heating or other purpose. Then the cooled liquid refrigerant with a higher pressure from the condenser flows through expansion A which causes the pressure to drop, when its pressure falls to certain pressure, then it flows into the flash-tank and becomes a mixture of vapor and liquid (4'). In the flash-tank, the over flash vapor

flows into the compressor through the supplementary inlet (6), which is called supplementary circuit. Because of the flash vapor evaporating continually, the below refrigerant is sub-cooled, then this sub-cooled refrigerant (5) flows through expansion valve B (5') and into the evaporator, which is called main circuit. In the evaporator, the refrigerant in the main circuit absorbs heat from the low temperature environment and becomes the vapor with low pressure and flows into the suction port of the compressor (1). The refrigerant from the suction port is compressed to certain pressure (2) by the compressor where the compression chamber is connected to the supplementary circuit. The two parts of refrigerant are mixed and compressed in the compression chambers (2') as the scroll compressor rotates until the compression chamber is cut off with the supplementary circuit. After that the mixed refrigerant is compressed to condensation pressure. The vapor with a high pressure and temperature from the compressor is discharged to the condenser (3) and then starts another cycle^[4].



(1) Principle Diagram of the Prototype



(2) lgP-h Diagram of the Prototype

Fig 1: Principle and lgP-h Diagram of the Prototype

3. THE CORRELATION OF ELECTRIC EFFICIENCY OF THE COMPRESSOR

In the simulation and calculation of the system, the electric efficiency of the compressor is used and it

is defined as $\eta_{el} = \frac{P_s}{P_{el}}$, where P_s is the isentropic

power of the compressor and P_{el} is electric power input of the compressor.

Electric efficiency of the compressor is different in different systems. The electric efficiency of the compressor in the heat pump system cannot be replaced by the empirical data or expression of the electric efficiency in conventional heat pump system. Even in the same system, electric efficiency varies with operation conditions. Therefore, the electric efficiency expression of the scroll compressor in the heat pump system with flash-tank must be fitted based on the experimental data of the heat pump prototype.

By the least square method, the electric efficiency expression of 5 Hp scroll compressor in the prototype is fitted as $\eta_{el} = 0.9696 \times e^{-0.122x}$, where x is the ratio of condensation pressure to evaporation pressure.

4. CALCULATION AND ANALYSIS OF THE PERFORMANCES

4.1 Errors Between the Calculated and Measured Values

Table 1: Comparison between Calculated and Measured Performances of the Prototype (Tk=45°C, To=-25°C)

Performances	Q_h (kW)	W (kW)	COPh	T_d (°C)
Calculated values	8.31	4.46	1.87	129.08
Measured values	8.15	4.60	1.77	132.77
Errors(%)	+1.96	-3.04	+5.65	-2.74

Table 2: Comparison between Calculated and Measured Performances of the Prototype (Tk=42°C, To=-25°C)

Performances	Q_h (kW)	W (kW)	COPh	T_d (°C)
Calculated values	7.79	3.96	1.97	128.03
Measured values	7.98	4.19	1.90	126.57
Errors(%)	-2.38	-5.49	+3.68	+1.15

Under the conditions of the evaporation temperature of -25 °C and the condensation

temperature of 42 °C and 45 °C respectively, the comparison between calculated and measured performances is shown in Table 1 and Table 2. It is obvious that the calculated value is very close to the relative measured ones. This demonstrates that the simulating and calculating results of the prototype are credible and reasonable.

Using the fitted expression of electric efficiency, the performances of the heat pump system can be calculated under the conditions of the condensation temperature from 30 °C to 50 °C and the evaporation temperature from -30 °C to 0 °C. As this study aims mainly at the prototype operating in the winter of cold regions, we here focus on analyzing its heating capacity, heating coefficient of performance, power input and discharge temperature.

4.2 Calculation and Analysis of the Performances

4.2.1 Heating Capacity

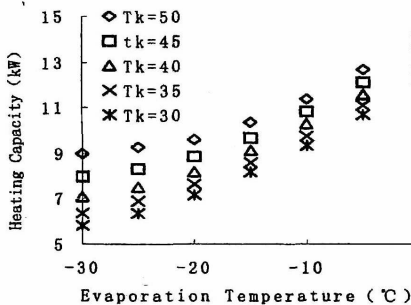


Fig. 2: Heating Capacity Curves

The variations of the heating capacity with the evaporation temperature are shown in Fig.2. When the condensation temperature is constant, the heating capacity of the system decreases linearly with the decrease of the evaporation temperature. It can be found that when the evaporation temperature is constant, the variation of the heating capacity with the condensation temperature is not obvious. The heating capacity of the system is 8.28kW under the conditions of the condensation temperature of 45 °C and the evaporation temperature of -25 °C, which can satisfy heating requirement in the winter of cold regions.

4.2.2 Heating Coefficient of Performance

The variations of heating coefficient of performance (COPh) with evaporation temperature are shown in Fig.3. It can be shown that COPh increases with increase of the evaporation temperature and with decrease of the condensation temperature. COPh of the system is 1.87 under the conditions of the condensation temperature of 45 °C and the evaporation temperature of -25 °C.

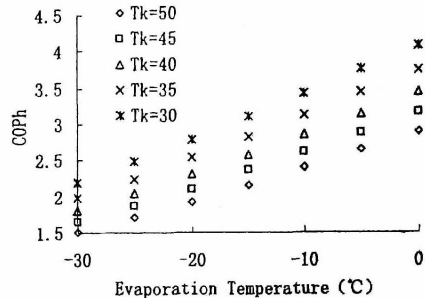


Fig. 3: COPh Curves

4.2.3 Power Input

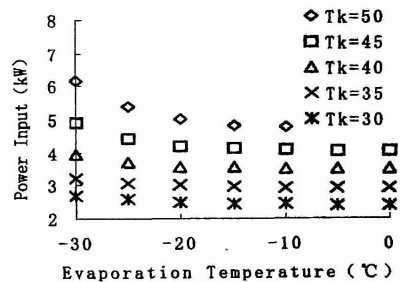


Fig. 4: Power Input Curves

The variations of power input with the evaporation temperature are shown in Fig.4. It can be shown that power input increases with decrease of the evaporation temperature and with increase of the condensation temperature. It is because the mass flowrate of the refrigerant from the evaporator to the compressor decreases obviously with decrease of the evaporation temperature when the condensation temperature is constant. However, the mass flowrate into the supplementary inlets of the compressor increases obviously with decrease of the evaporation temperature. Therefore, the total mass flowrate of the refrigerant from the compressor to the condenser is constant approximately with decrease of the evaporation temperature. However, the compression ratio of the compressor increases, which leads power input to increase^[4]. It can be shown that the variation rate of the power input is not big when evaporation temperature is more than -20 °C, and relatively great when the evaporation temperature is lower than -20 °C.

The power input of the system is 4.44kW under the conditions of the condensation temperature of 45 °C and the evaporation temperature of -25 °C, which is less than the rated power input of the compressor, namely 4.55kW.

4.2.4 Discharge Temperature

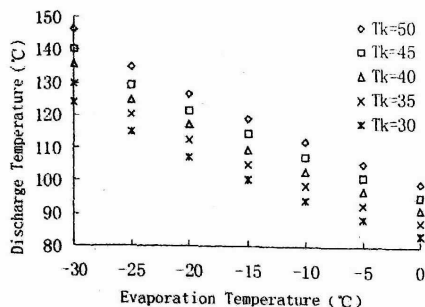


Fig. 5: Discharge Temperature Curves

The variations of the discharge temperature with the evaporation temperature are shown in Fig.5. It can be shown that the discharge temperature increases with decrease of the evaporation temperature and with increase of the condensation temperature. The discharge temperature is lower than 130°C under the conditions of the condensation temperature of 45°C and the evaporation temperature of -25°C, which can satisfy reliable operation of the compressor.

5. CONDITION SWITCHING ON/OFF THE SUPPLEMENTARY PIPE

When the solenoid valve in the supplementary pipe is turned off, the system with flash-tank becomes a conventional heat pump system. The performances of these two systems under the conditions of the condensation temperature of 45 °C and the evaporation temperature of -15 °C and -12 °C respectively^[2] are shown in Table 3 and Table4.

Comparing with the conventional heat pump system, the increasing rate of the heating capacity of the flash-tank system is from 16.45% to 8.06%, and the rate of the power input is from 7.87% to 4.33%, and the rate of heating COP is from 7.76% to 3.70%, the discharge temperature decreases remarkably. It demonstrates that the performance improvement of the flash-tank system becomes smaller gradually with the increase of the evaporation temperature. When the evaporation temperature is higher than -10°C, the flash-tank system performs very closely to the conventional system although the former has better performances. So the evaporation temperature of -10 °C can be suggested as the condition switching on/off the supplementary pipe.

Table 3: Comparison of the performances between Flash-Tank System and Conventional system (Tk=45°C, To=-15°C)

System	Q _h (kW)	W (kW)	COP _h	T _d (°C)
Conventional System	8.33	3.81	2.19	134.97

Prototype	9.70	4.11	2.36	114.58
Difference	16.45%	7.87%	7.76%	-20.39

Table 4: Comparison of the performances between Flash-Tank System and Conventional system (Tk=45°C, To=-12°C)

System	Q _h (kW)	W (kW)	COP _h	T _d (°C)
Conventional System	9.55	3.93	2.43	129.60
Prototype	10.32	4.10	2.52	110.24
Difference	8.06%	4.33%	3.70%	-19.36

6. CONCLUSIONS

Through the above analysis of the heat pump system with flash tank, we conclude as follows:

- (1) The prototype can operate steadily under the conditions of the evaporation temperature of -25°C and the condensation temperature of 45°C, its heating capacity can satisfy the heating requirement in the winter of cold regions.
- (2) The vapor injection to scroll compressor can increase the heating capacity and improve the heating performances of the heat pump system. But the improvement becomes smaller and smaller with increase of the evaporation temperature, and the evaporation temperature of -10 °C can be suggested as the condition switching on/off the supplementary pipe.

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